Administrative Report to Bureau of Land Management: Potential ground-water impacts from coal-bed methane development in portions of Montana

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Introduction

The purpose of this report is to provide a general discussion of potential ground-water impacts from the development of coal-bed methane (CBM) in selected areas of Montana. The impacts addressed include reduction in hydrostatic head in coal aquifers, discharge rates from producing coal-bed methane wells, and ground-water recovery potential.

The primary area of analysis is the Powder River Basin (PRB) in southeastern Montana. Coal seams in this area are within the Tongue River Member of the Fort Union Formation, and are the major aquifers in the area for private wells. The coals also provide water to a significant percentage of springs. Due to their status as aquifers, drawdown within these coal seams is an important consideration for development of CBM. A similar situation exists in the Bull Mountains, where the coals are also in the Tongue River Member.

Outside the Fort Union Formation coal areas, but within areas considered for this report, the coal seams are not considered aquifers. In these areas, reduction in ground-water pressure is less important, however discharge rates from producing CBM wells are important to know for calculations of impacts to receiving waters and disposal options.

The areas considered in this report were selected by the Bureau of Land Management and are shown on Figure 1. These areas are those with inventoried coal reserves, plus several speculative areas identified by CBM companies. The actual CBM reserves are not known for any of the areas evaluated, and therefore the number of CBM wells and years of production cannot accurately be determined.

Data Sources

The estimated number of CBM wells in each area were provided by the Miles City office of the BLM. These numbers were based on total coal tonnage reported for these areas in resource assessments.

The primary sources of hydrogeologic data were published reports from studies done during the coal assessment work of the 1970's and early 1980's. Many of these studies were funded by BLM and the work carried out by BLM, MBMG, U.S. Geological Survey and others. In addition to publications, data were retrieved from mine company permit applications on file with the State of Montana, Department of Environmental Quality, Industrial and Energy Minerals Bureau in Billings, Montana. A complete list of data sources is in the Reference section at the end of this report.

The available hydrogeologic data for the Powder River Basin and the Bull Mountain coal fields provide an accurate description of the ground-water systems. Hanging Woman Creek watershed is particularly well described in several studies. Data

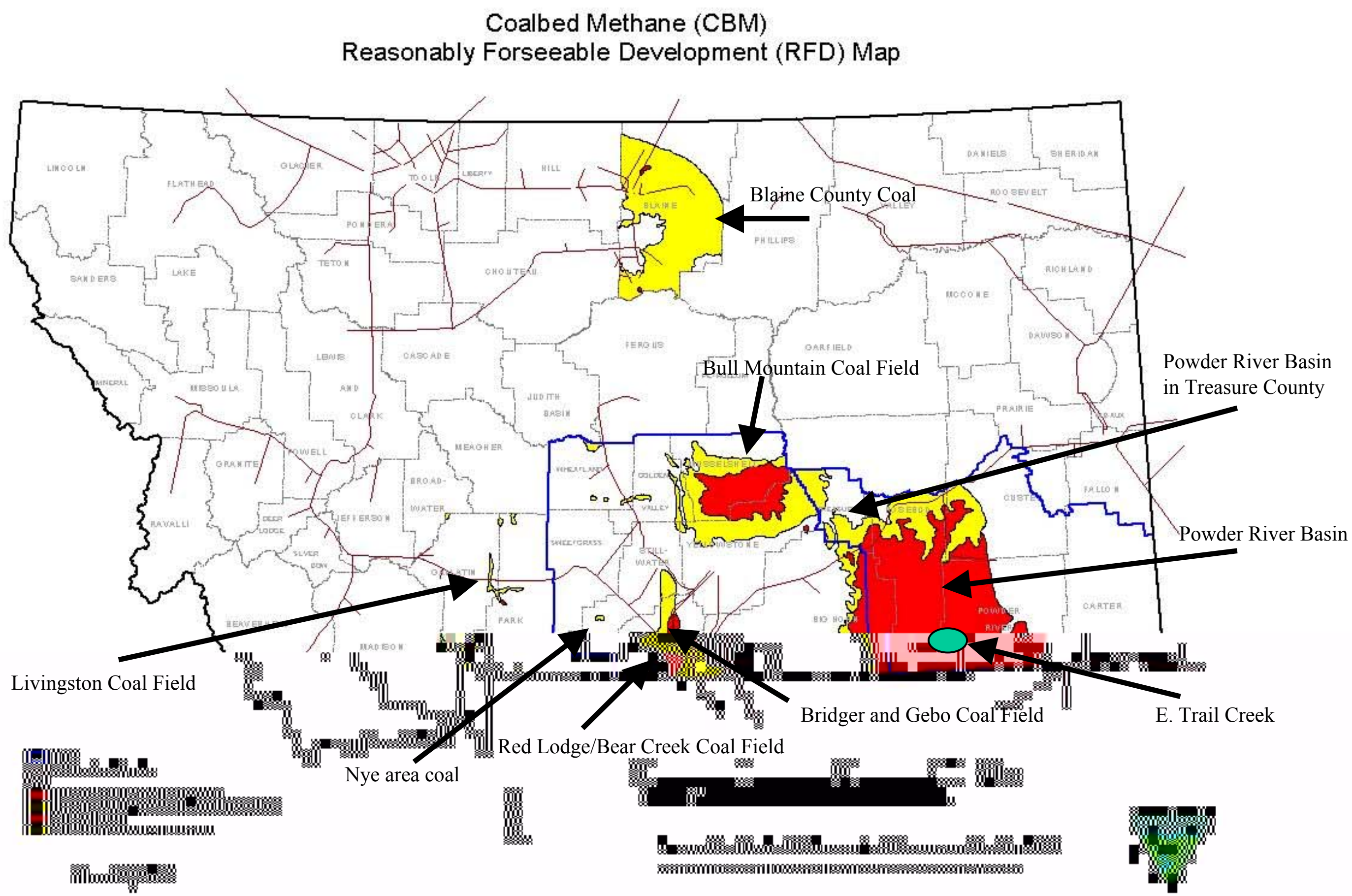

Figure 1 Areas Evaluated for CBM Impacts

for these areas provide aquifer characteristics for the coal seams and to a lesser degree for the shallow sandstone units. Data include aquifer test results, water level measurements and lithologic descriptions. The data from these coal studies is generally limited to those portions of the coal fields with less than about 200 feet of overburden since the purpose was to identify areas where strip mining could be economically feasible.

Outside the Powder River Basin and the Bull Mountains the available hydrogeologic data are limited. Lithologic descriptions of the coal seams and overburden are available for all areas except Nye and Blaine county. Some hydrogeologic data for the Red Lodge/Bear Creek area are in a company mine permit (Beartooth Coal Company, Brophy #2 Mine Permit Application). For other areas, no site-specific hydrogeologic data were found. No aquifer test results were found for Eagle or Judith River coal seams.

Where site specific data were not available, estimates were made based on other areas that seemed most likely to be similar. In some cases, where no data were available, assumptions were made based on company input received by BLM. If no coal descriptions were available, a minimum thickness of 20 ft was assumed, based on the minimum required coal thickness reported to the BLM by CBM companies. Likewise, the minimum starting head (hydrostatic pressure in the aquifer prior to production pumping) was assumed to be 200 ft unless site-specific water level data were available showing a lower value. Results from 2 aquifer tests of the Morrison Coal near Stockett were selected as the best available representation of aquifer characteristics in the Cretaceous coals (MBMG file data).

Methods

Description of Development and Anticipated Impacts

CBM development involves drilling and completing wells in coal seams, pumping water from the coal seam, discharging the water and collecting the produced gas from the well. Water is pumped from the coal seam to reduce hydrostatic pressure and allow the methane to desorb from the coal surfaces. Reduction in pressure at the well creates a roughly circular cone of depression around the well, with greatest drawdown near the well and decreasing drawdown away from the well. Wells are installed in fields with spacing between wells such that sufficient drawdown is achieved to allow methane to desorb across the entire well field or project area.

Computer Modeling

Single-layer, two-dimensional flow of ground-water flow through a confined aquifer is simulated using Ground Water Vistas pre- and post-processing software and MODFLOW (McDonald and Harbaugh, 1998) and (Rumbaugh and Rumbaugh, 1998). Steady-state and transient conditions are simulated using the same hydrologic conditions. Grid spacing is set uniform in both directions, using 660 ft cells in the 25 square-mile (mi2) center of the model, with spacing increasing outside the center by 50% per row and column to a maximum of 38,058 feet at the edges. The total model dimension is about 65 miles in each direction. Due to the topographic relief in southeastern Montana, and discontinuities in coal seams, there are not likely to be any locations where a CBM development is more than 30 miles from a boundary such as the coal outcrop or subcrop.

Initial heads for the model are set at 200 feet above the top of the coal, and constant head boundaries are on the east and west edges of the model. CBM wells are simulated as constant head cells, with the head at 10 feet above the top of the coal (190 feet of drawdown). Wells are located on 80-acre spacing. For most runs, 100 wells are simulated in a 10 well by 10 well grid. Using a set number of wells allowed analysis of hydrogeologic parameters. Hydraulic conductivity and storativity are varied for each model run as described in later sections of this report.

Steady-State Simulations

Three steady-state simulations were run; hydraulic conductivity was varied from 0.1, to 1, and 10 feet per day. In all three cases, the cone of depression caused by the well field intercepted the boundaries at the edges of the model. Given the extremely large model area (65 miles square) it is apparent that using steady-state simulations will over-estimate the extent of the cone of depression.

Transient Simulations

Transient simulations were run using variations of hydraulic conductivity and storage coefficient values. The model was used to simulate 20 time steps of 365 days each for a total of 7,300 days (about 20 years). In several cases, the cone of depression reached the edges of the model before 20 years; the simulation was considered invalid at this point in time. In the simulations where the boundaries were reached, the last time step before the cone reached the boundary was used as the maximum extent. Recovery simulations were run using the final head values from the pumping simulation, and eliminating the constant head cells representing pumping wells. The recovery was started at the last valid time step of the pumping simulation and run for a maximum of 20 years or until boundary effects were observed.

Comparison to other Related Impacts

To evaluate the validity of the computer modeling, the model results are compared to known impacts that are considered to be similar in scope and magnitude. Large scale coal strip mining, such as that at Colstrip and Decker, Montana, cause water level responses that may approximate CBM development. Through gravity drainage at pit faces, coal mines completely dewater adjacent coal seams. For example, the West Decker Mine covers an area of about 4 square miles, and after 20 years of mining 10 feet of drawdown was recorded at a distance of about 4 miles from the mine (Van Voast and

Reiten, 1988). Similar drawdown is noted in the Colstrip area near the Rosebud and Big Sky mines. In Wyoming, drawdown is also apparent at distances of 4 miles from coal mines (Hydro-Engineering, LLC, 2000, Figure 8). In much of the area covered by the GAGMO 2000 Annual Report (Hydro-Engineering, LLC, 2000) the drawdown due to CBM production exceeds that caused by coal-strip mines.

Data from Wyoming indicate 5 feet of drawdown around existing coal mines after 15 years of mining at distances ranging from about 2 to 14 miles (BLM, 1999). Five feet of drawdown was described as the maximum extent of drawdown for the Wyodak EIS. Ground water modeling for the Wyodak EIS indicated 5 feet of drawdown at distances of between 10 and 22 miles from the edge of dense CBM development.

Drawdown caused by coal mines and existing CBM production in the Powder River Basin indicates that future CBM production can be expected to cause water-level declines of 10 ft or more, at distances in excess of 4 miles.

Anticipated Results

This study was undertaken to determine a set of ranges of possible water-level drawdown, discharge rates and recovery for a given set of hydrogeologic input parameters. The results are considered defensible within the constraints of the data assumptions and the type of modeling chosen. Computer modeling cannot calculate actual site-specific impacts, but rather can provide an analysis of possible impacts based on the available data. For this preliminary analysis, the models were limited to two-dimensional, single layer systems. This approach allows no vertical leakage, or recharge to the coal seam, and therefore drawdown and recovery results describe what is considered to be the extreme impact, while discharge rates are underestimated.

The range of values presented bracket the expected hydrogeologic conditions for CBM areas in Montana, based on the results of aquifer test in published reports and mine permits for this portion of Montana (data on file at MBMG). Proposed future development scenarios can be compared to the ranges presented here, allowing a discussion of possible impacts.

Several assumptions are necessary to calculate impacts to a ground-water system. Changes in the number of wells, timing and duration of pumping from those wells, and aquifer characteristics will all change the calculated results. In the model, all wells begin pumping simultaneously, whereas in actual development wells will come on line in pods, one pod at a time over a period of up to 10 years. Some wells will be plugged during this time, having reached the end of production while new wells are being installed. This causes the modeled drawdown to be very symmetrical around the development, and to cover a somewhat larger area than actual development would cause after 20 years. For the purpose of calculations, the life-of-wells was set at 20 years. Actual well life may be much less than this, decreasing the total drawdown period and magnitude of drawdown.

The final version of this report, schedule for completion late in 2001, will include a multi-layer, 3-dimensional model for the East Trail Creek area of the Hanging Woman Creek watershed. This model will refine the analysis of impacts by allowing vertical leakage. The expected difference between the single-layer and multi-layer model are less drawdown, greater recharge, and larger pumping rates predicted by the multi-layer model. To help calibrate the 3-dimensional model, pumping rates and drawdown at the Squirrel Creek project will be used to determine a reasonable vertical leakage factor.

Site and Production Descriptions

For the purpose of this analysis, all development scenarios were assumed to be constructed with 1 well per coal seam on each 80-acre tract of the field. Using the number of wells anticipated for each field (provided by BLM, Miles City) the total area was calculated using 8 wells per square mile. In areas with multiple coal seams, the total well count provided by BLM was divided by the likely number of coal seams. Anticipated maximum life of production from each well is 20 years, and this duration was used for transient modeling. All wells within a coal field were simultaneously turned on, for the purpose of modeling.

Results

Generic Impact Descriptions

The input and results of each of 12 simulations are presented below. These are presented in groups of three where K is constant, S is varied, and geometric mean, high and low values for the Powder River Basin are used. The range and values for data input to the model are listed in Table 1. The generic models are all based on a 100 well CBM unit, using 200 feet of starting head.

Results of twelve modeling scenarios are presented in Table 2. As predicted by standard hydrogeologic theories, higher values for storativity result in smaller areas of drawdown, larger discharge rates, and faster recovery. The inverse is true for lower storativity values. Higher transmissivity yields larger areas of drawdown, greater discharge, and faster recovery. The results for lower transmisivity values are the opposite.

Combined discharge rates from the constant head cells representing CBM production wells were calculated for each annual time step. Figure 2 shows discharge rates for the model runs for 1 standard deviation greater than and 1 standard deviation less than the geometric mean of hydraulic conductivity value for Fort Union coal seams. The rates shown are the average flux per well, which was calculated by dividing the total flux from the model by the number of wells. Discharge decreases with time for the constant head cells (producing wells). Like drawdown and recovery, discharge is sensitive to hydraulic conductivity and storativity.

Table 1. Aquifer characteristics for potential coal-bed methane areas in Montana used for modeling ground-water impacts. (page 1)

Coal Field Name	Estimated CBM Area (square miles)	Estimated Number of CBM Wells	Well spacing (acres)	Coal Name(s)	Possible Number of coal seams developed
Powder River Basin					
PRB General	678	5594	80	Fort Union Fm	3
Hanging Woman	40	320	80	Anderson, Dietz, Canyon	3
Treasure County, PRB	1	8	80	Fort Union Fm	1
Bull Mountains	12.5	100	80	Mammoth/Rehder	1
Carbon County					
Bear Creek/Red Lodge	9	70	80	Fort Union Fm (#3, 4, 6)	3
Bridger	5	40	80	Eagle Fm	1
Gebo	5	40	80	Eagle Fm	1
Stillwater County (Nye)	5.5	45	80	Eagle Fm	1
Blaine County	1	8	80	Judith River Fm	1
Gallatin and Park Counties (Livingston)	2	16	80	Eagle Fm	1

Table 1. Continued (page 2)

Coal Field Name	Aquifer Thickness (ft)	Aquifer Thickness (ft)	Aquifer Thickness (ft)	Lithologic gradient (ft/ft)	Lithologic dip	Static Water Level Above top of coal (ft)	Hydraulic Gradient (ft/ft)	Flow direction
Powder River Basin								
PRB General	3	27	96	0		200	0.002	N
Hanging Woman	26	27	33	0		108	0.008	W
Treasure County, PRB		20		0		200	0.002	N
Bull Mountain s		11		0.01	NW	75	0.007	NW
Carbon County								
Bear Creek/Red Lodge	4	10	11	0.21	SW	200		SE
Bridger		5		0.06	W	325	0.008	NE
Gebo		5		0.06	W	200	0.008	NE
Stillwater County (Nye)		5				200		
Blaine County		4		0		200		
Gallatin and Park Counties (Livingston)		10		0.58		200		

Table 1. Continued (page 3)

	Hydraulic Conductivity			Transmissivity			Storativity		
	Low	Mean	High	Low	Mean	High	For Low K	For Mean K	For High K
Coal Field Name					T	T	S	S	S
					(ft2/d)	(ft2/d)			
Powder River Basin									
PRB General	0.3	2.8	26.3	6	56	526	2.E-03	6.E-05	6.E-05
Hanging Woman	0.1	0.5	3.3	1.4	12.3	108.8	3.E-05	1.E-04	6.E-04
Treasure County, PRB	(0.1)	(1)	(10)	(1)	(10)	(20)	(1E-5)	(1E-4)	(1E-3)
Bull Mountain s	0.02	0.1	0.4	0.2	1.0	4.4	8.E-06	9.E-05	1.E-03
Carbon County									
Bear Creek/Red Lodge	(0.1)	(1)	(10)	(1)	(10)	(20)	(1E-5)	(1E-4)	(1E-3)
Bridger	(.004)	(0.04)	(0.4)		(0.2)			(1E-4)	
Gebo	(.004)	(0.04)	(0.4)		(0.2)			(1E-4)	
Stillwater County (Nye)	(.004)	(0.04)	(0.4)		(0.2)			(1E-4)	
Blaine County	(.004)	(0.04)	(0.4)		(0.2)			(1E-4)	
Gallatin and Park Counties (Livingston)	(.004)	(0.04)	(0.4)		(0.4)			(1E-4)	

Table 1. Continued (page 4)

Coal Field Name	Comments	References
Powder River Basin		
PRB General	Well count is for one coal seam	(see reference section)

Table 2. Results of generic modeling runs.

K = 0.1 feet per day

K:	0.1 (feet per day)
T:	2 (ft2/day)
S:	7E-6 (dimensionless)
Model boundary reached:	after 5 years
Drawdown at 10 miles:	10 feet in 5 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	150 feet in 20 years

K:	0.1 (feet per day)
T:	2 (ft2/day)
S:	1E-4 (dimensionless)
Model boundary reached:	not reached in 20 years
Drawdown at 10 miles:	0 feet in 20 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	100 feet in 20 years

K:	0.1 (feet per day)
T:	2 (ft2/day)
S:	1E-3 (dimensionless)
Model boundary reached:	not reached in 20 years
Drawdown at 10 miles:	0 feet in 20 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	80 feet in 20 years

K = 1.0 feet per day

K:	1.0 (feet per day)
T:	20 (ft2/day)
S:	7E-6 (dimensionless)
Model boundary reached:	after 5 years
Drawdown at 10 miles:	15 feet in 5 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	77 feet in 5 years

Table 2. Results of generic modeling runs (continued)

K:	1.0 (feet per day)
T:	20 (ft2/day)
S:	1E-4 (dimensionless)
Model boundary reached:	after 5 years
Drawdown at 10 miles:	5 feet in 5 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	138 feet in 10 years

K:	1.0 (feet per day)
T:	20 (ft2/day)
S:	1E-3 (dimensionless)
Model boundary reached:	not reached after 20 years
Drawdown at 10 miles:	0 feet in 20 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	100 feet in 20 years

K = 10 feet per day

K:	10 (feet per day)
T:	200 (ft2/day)
S:	7E-6 (dimensionless)
Model boundary reached:	before 1 year
Drawdown at 10 miles:	model not valid
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	model not valid

K:	10 (feet per day)
T:	200 (ft2/day)
S:	1E-4 (dimensionless)
Model boundary reached:	after 1 year
Drawdown at 10 miles:	11 feet in 1 year
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	100 feet in 1 year

K:	10 (feet per day)
T:	200 (ft2/day)
S:	1E-3 (dimensionless)
Model boundary reached:	after 3 years
Drawdown at 10 miles:	1.5 feet in 3 years
Maximum drawdown:	190 feet (constant head cells)
Maximum recovery:	125 feet in 5 years

Table 2. Results of generic modeling runs (continued)

Low Values for Fort Union coal seams

K (feet per day):	0.3 (feet per day)
T:	6 (ft2/day)
S:	2E-3 (dimensionless)
Model boundary reached:	not reached after 20 years
Drawdown @ 5 miles:	0 feet
Maximum drawdown:	190 feet (constant head cells)
5 feet of drawdown @:	3 miles
Flux range:	215k to 14k cfd @ 100 wells
Maximum valid model duration:	20 years

Mean Values for Fort Union coal seams

K (feet per day):	2.8 (feet per day)
T:	56 (ft2/day)
S:	6E-5 (dimensionless)
Model boundary reached:	after 1 years
Drawdown @ 5 miles:	31 feet
Maximum drawdown:	190 feet (constant head cells)
5 feet of drawdown @:	11 miles
Flux range:	80k to 30k cfd @ 100 wells
Maximum valid model duration:	1 year

High Values for Fort Union coal seams

K (feet per day):	26.3 (feet per day)
T:	526 (ft2/day)
S:	6E-5 (dimensionless)
Model boundary reached:	less than 1 year
Drawdown @ 5 miles:	*40 feet
Maximum drawdown:	190 feet (constant head cells)
5 feet of drawdown @:	*20 miles
Flux range:	*380 - 250k cfd @ 100 wells
Maximum valid model duration:	*Model not valid

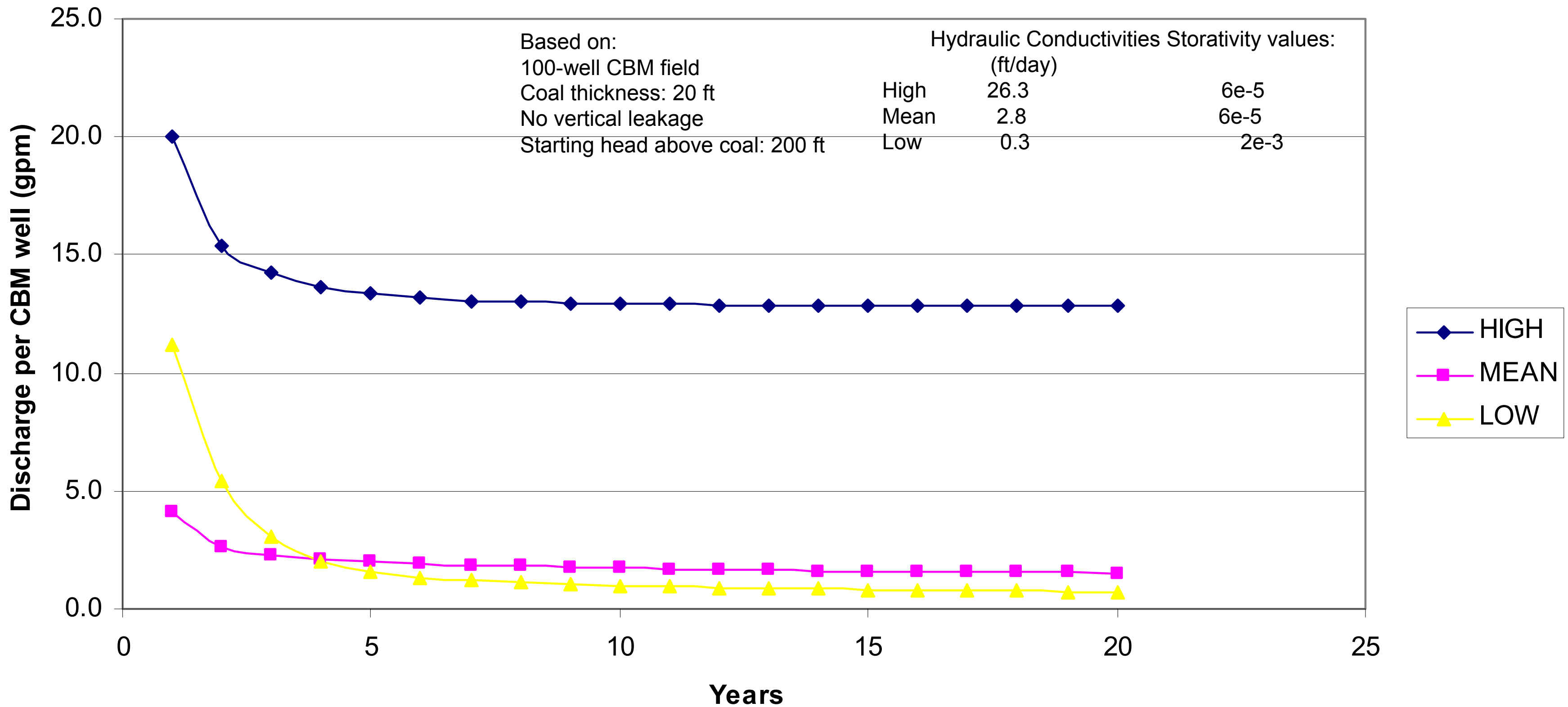

Figure 2. Average discharge rates for individual CBM wells with time, for high and low transmissivity and storativity valus.

Combined discharge rates from the constant head cells representing CBM production wells were calculated for each annual time step. Figure 2 shows discharge rates for the model runs for 1 standard deviation greater than and 1 standard deviation less than the geometric mean of hydraulic conductivity value for Fort Union coal seams. The rates shown are the average flux per well, which was calculated by dividing the total flux from the model by the number of wells. Discharge decreases with time for the constant head cells (producing wells). Like drawdown and recovery, discharge is sensitive to hydraulic conductivity and storativity.

Modeled drawdown and discharge rates are much less sensitive to the size of the well field as to the other hydraulic parameters. Model runs were made using hydraulic conductivity equal to 1.2 ft/d and storativity equal to 1E-4, for 100, 200 and 400 simulated producing wells. Table 3 lists the distance from the edge of the simulated well field, size of field, and amount of drawdown for these runs.

Table 3. Relationship between number of simulated wells and drawdown after 5years. Hydraulic conductivity is 1.2 ft/day and storativity is 1E-4.

No. of wells	Well field dimensions	Drawdown at distance	Drawdown at distance
100	3.5 miles square	44 ft at 5 miles	5 ft at 12 miles
200	5 miles square	57 ft at 5 miles	5 ft at 13.1 miles
400	7 miles square	63 ft at 5 miles	5 ft at 14 miles

As the number of adjacent producing wells increases, the total discharge increases, however the average discharge from each well decreases. In other words, the rate of increase in total discharge from a CBM field increases at a slower rate than does the number of producing wells in that field. Average discharge rates for 3 sizes of field development (100, 200, and 400 wells) are shown on Figure 3. Wells on the perimeter of the field can yield water from both storage release and flux through the aquifer outside the field but within the cone of depression. Wells in the central portion of a field can only produce water released from storage, and as the available head is reduced the quantity of water that can be produced from storage decreases.

Site-Specific Impact Descriptions

The specific coal fields identified by BLM for inclusion in this analysis are shown on Figure 1. Sufficient data for detailed site specific modeling is generally not available. Site specific data or approximations based on similar coal age and characteristics can be used to estimate drawdown, pumping rate and recovery by comparison to the generic models. Hydraulic conductivity values are based on the geometric mean, plus (high) and minus (low) one standard deviation unit. Storativity values were chosen from those aquifer tests that had hydraulic conductivity values near the mean, high and low. Transmissivity values are based on the hydraulic conductivity values multiplied by the coal seam thickness. All values are listed in Table 1.

Powder River Basin

A map showing a possible development scenario for the Powder River Basin in Montana is presented in Figure 4. This map represents 5,594 CBM wells within a single coal seam, covering an area of 678 square miles in the most likely methane producing areas, based on Van Voast (2001). Aquifer characteristics are listed in Table 1. The geometric mean hydraulic conductivity (K) value for the PRB coal aquifers is 2.8 ft/d, and the storativity associated with this K value is 6E-5. Within the range of hydraulic conductivity values analyzed, the PRB values are high and indicate that discharge rates will be higher in this area than other areas. Storativity is typical for the range of values for coal in Montana. The distance of significant drawdown surrounding developed CBM fields can be expected to be in the upper-range of the modeled results, reaching 5 feet at distances of 11 miles. In the case of full field development, based on the model assumption of simultaneous startup, drawdown can be expected to reach the coal outcrop at areas of the PRB except to the south where drawdown would cross into Wyoming. Where the cone of depression encounters no-flow boundary conditions such as dry outcrop areas, drawdown in other areas will increase. Average well discharge rates are expected to fall in the center of Figure 2 based on the modeled scenarios.

East Trail Creek, tributary to Hanging Woman Creek

This area has received more research attention than most other areas where CBM development is considered likely. Within the 40 square mile watershed a total of 320 CBM wells per developed coal seam are projected. Aquifer characteristics are listed in Table 1. The mean hydraulic conductivity value for the East Trail Creek area coal aquifers is .5 ft/d, and the mean storativity is 1E-4. Within the range of transmissivity values analyzed, these values are lower than the Powder River Basin-wide values, storativity is typical, and discharge rates are expected to be in the mid-range of Figure 2. Given the assumed field size of 40 square miles and 320 wells, and based on the model of 100 wells plus the effects of the larger well field, drawdown at 5 feet or greater can be expected to cover areas as far as 13 miles from the center of development (10 miles from the edges) after 5 years.

Powder River Basin in Treasure County

Fort Union Formation coal seams within Treasure County have received very little attention but were identified by the analysis of potential producing areas by BLM. Within this area 8 CBM wells within 1 square mile may be developed. Aquifer

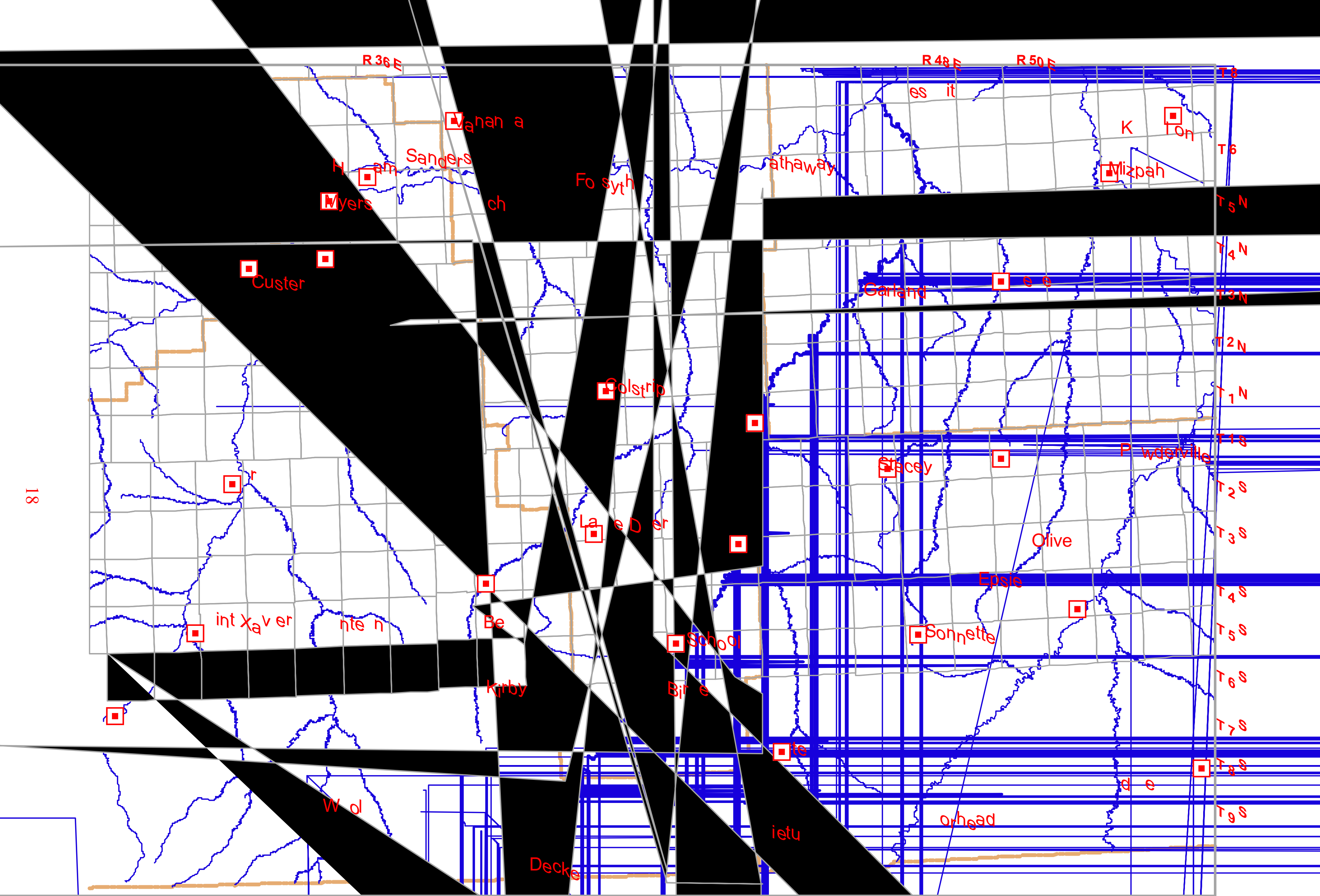

Figure 4. Based on 80 acre spacing, de[redacted]5,59[redacted]BM wells in [redacted]would co[redacted]78 square miles. If developed in adjacent fields, starting near Wyoming, [redacted]velopm[redacted]might cover[redacted] the o[redacted]e sho[redacted]

characteristics are listed in Table 1. No site specific data area available, therefore mean values for the PRB (rounded to 1 significant figure) were used to assess impacts for this area. The mean hydraulic conductivity value used for Treasure County area coal aquifers is 1 ft/d, and the mean storativity is 1E-4. Based on these values, discharge rates will likely be in the lower portion of Figure 2. Transmissivity and storativity are typical for the range of values for coal in Montana, however the number of potential wells is much lower. Therefore the distance of significant drawdown surrounding developed CBM fields can be expected to be much smaller than the mid-range of the modeled results.

Bull Mountain Coal Field in Musselshell and Yellowstone counties

Several research studies and a mine permit application provide data specific to the coal seams of the Bull Mountains. A total of 100 CBM wells developed in the Mammoth/Rehder coal seam is considered likely, which would cover an area of 12.5 square miles. Aquifer characteristics are listed in Table 1. The mean hydraulic conductivity value for the Bull Mountain coal aquifers is 0.1 ft/d, and the mean storativity is 9E-5. Within the range of values analyzed, these values are fairly low for Fort Union coal and indicate that discharge rates will be lower in this area than other areas (Figure 2). Storativity is typical for the range of values for coal in Montana, and the distance of significant drawdown surrounding developed CBM fields can be expected to be in the mid-range of the modeled results. Drawdown, based on the modeled scenario, may be limited to areas less than 10 miles from the edge of the well field even after 20 years. However, the Mammoth Coal does not exceed a width of more than about 7 miles at any location. Therefore, even 3 miles of drawdown will reach outcrop areas and may reduce ground-water pressure in the entire system due to full field development.

Red Lodge/Bear Creek Coal Field in Carbon County

Although there have been several geologic studies and a coal mine permit, only limited hydrogeologic data are available for the Fort Union Fm coal seams in Carbon County. Seventy CBM wells per developed coal seam, over an area of 9 square miles is considered likely. Aquifer characteristics listed in Table 1 are estimates based on other Fort Union Formation coal seams. The estimated mean hydraulic conductivity value for the Bear Creek/Red Lodge area coal aquifers is 1 ft/d, and the mean storativity is 1E-4. Within the range of values analyzed, these estimated values are typical for the Powder River Basin-wide values. Based on these parameters, discharge rates will be near the middle of those on Figure 2. Storativity is typical for the range of values for coal in Montana, and the distance of significant drawdown surrounding developed CBM fields can be expected to be in the mid-range of the modeled results. Drawdown of 5 feet is modeled to reach 10 miles from the edge of development after 5 year.

Bridger and Gebo Coal Field in Carbon County

No site specific hydrogeologic data are available for the Bridger and Gebo coal fields in Carbon County. Geologic data are available. In both fields 40 CBM wells developed in the Eagle formation coal seam is considered likely, covering an area of 5 square miles. Estimated aquifer characteristics are listed in Table 1. No aquifer test data or results were found for Eagle Formation coal. The data that were considered the most applicable were results from two aquifer tests performed by MBMG on Morrison Formation coals near Stockett. The age and grade of the Morrison Formation coal more closely approximates that of the Eagle Fm than do the Fort Union coal seams. The estimated mean hydraulic conductivity value for coal aquifers in this area is 0.04 ft/d, and the mean storativity is 1E-4. Within the range of values analyzed, these values are low and indicate that discharge rates will be lower in this area than other areas. Estimated storativity is typical for the range of values for coal in Montana, the potential number of wells in each field is low, and the distance of significant drawdown surrounding developed CBM fields can be expected to be well below the mid-range of the modeled results. Drawdown of 5 feet or greater would be expected to reach only a few miles from the well field, based on the modeled scenario.

Livingston Coal Field in Gallatin and Park counties

No site specific hydrogeologic data are available for the Livingston coal fields in Park and Gallatin counties. Geologic data are available. In this field 16 CBM wells developed in the Eagle formation coal seam is considered likely, covering an area of 2 square miles. Estimated aquifer characteristics are listed in Table 1. No aquifer test data or results were found for Eagle Formation coal, so data from the Morrison Formation coals near Stockett were used as estimates. The estimated mean hydraulic conductivity value for coal aquifers in this area is 0.04 ft/d, and the mean storativity is 1E-4. Within the range of values analyzed, these values are low and indicate that discharge rates will be lower in this area than other areas. Storativity is typical for the range of values for coal in Montana, the number of potential wells is very low, and the distance of significant drawdown surrounding developed CBM fields can be expected to be much less than the mid-range of the modeled results.

Nye area coal in Stillwater County

No site specific hydrogeologic or geologic data are available for the coal field near Nye in Stillwater County. In this field 45 CBM wells developed in the Eagle formation coal seam is considered likely, covering an area of 5.5 square miles. Estimated aquifer characteristics are listed in Table 1. No aquifer test data or results were found for Eagle Formation coal, so data from the Morrison Formation coals near Stockett were used as estimates. The estimated mean hydraulic conductivity value for coal aquifers in this area is 0.04 ft/d, and the mean storativity is 1E-4. Within the range of values analyzed, these values are low and indicate that discharge rates will be lower in this area than other areas. Storativity is typical for the range of values for coal in Montana, the number of potential wells is low, and therefore the distance of significant drawdown surrounding developed CBM fields can be expected to be below the mid-range of the modeled results.

Blaine County Coal

No site specific hydrogeologic or geologic data are available for coal fields in Blaine County. In this field 8 CBM wells developed in the Eagle formation coal seam is considered likely, covering an area of 1 square mile. Estimated aquifer characteristics are listed in Table 1. No aquifer test data or results were found for Eagle Formation coal, so data from the Morrison Formation coals near Stockett were used as estimates. The estimated mean hydraulic conductivity value for coal aquifers in this area is 0.04 ft/d, and the mean storativity is 1E-4. Within the range of values analyzed, this value is low and indicates that discharge rates will be lower in this area than other areas. Storativity is typical for the range of values for coal in Montana, the number of potential wells is very low, and the distance of significant drawdown surrounding developed CBM fields can be expected to be far below the mid-range of the modeled results.

Results of violations of assumptions

Single layer, 2-dimensional modeling requires a number of assumptions which are described earlier. Coal aquifers are not heterogeneous and isotropic, as assumed here. Real conditions will cause the shape of the cones of depression around CBM fields to have irregular shapes, extending farther in one direction than another. Errors and lack of data for aquifer parameters will cause erroneous model results. Higher values of transmissivity will allow greater discharge rates and larger drawdown, higher storativity will create smaller cones of depression and larger discharge rates.

The most important parameter that will be violated by real world conditions is vertical leakage. To date, no vertical hydraulic conductivity data are available for the PRB in Montana. Vertical leakage from overlying (or in some cases underlying) aquifers will decrease the drawdown effects, accelerate recovery and allow larger discharge rates. A very small vertical hydraulic conductivity value can have a very strong effect.

Generally speaking, it is poor practice to use Dirichlet (prescribed head or constant head) boundary conditions in modeling since there are few equivalent conditions in nature. The constant head boundary can produce or consume as much water as is necessary to maintain the head in that cell; flux into and out of these cells can far exceed what would be expected in nature. The simulations presented here use constant heads exclusively for both recharge and discharge. As such, these simulations are not intended to represent field conditions, but rather as a means of comparing the effects of hydraulic conductivity and storage coefficient across a range of values. It is emphasized that the results presented here are to be compared to other results within this report - not the results from other reports nor field data.

Summary

Steady state modeling is not a viable technique for this type of assessment. Generic transient modeling does not work well for predictions of site-specific impacts from development of this type. It does, however, provide some general indications that drawdown will be significant, recovery will take many years, and discharge will decrease significantly with time. Site specific data and 3-dimensional modeling is needed if specific drawdown and discharge is important to the analysis of impacts. Site specific modeling may work well, however it requires much more time and data.

The range of area of significant impact is considered for this modeling excersize to be 5 feet of drawdown. It is probably more important to know where this amount of drawdown may occur than the location of the 0 line of drawdown.

Generally, both storativity and hydraulic conductivity are crucial to understanding the magnitude of potential impacts. Storativity has a stronger effect on the calculations than does hydraulic conductivity. Size of development is less important, as the shape of the cone of depression changes little outside the CBM field for large or small fields.

Discharge rates should not be discussed without an associated time frame. The models show that discharge rates will decrease with time, and this should be included in any discussion of disposal. Also, any wells near the center of a field will have lower rates than those near the edge of the field.

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